Lepton Flavour Universality and anomalies in b→sll decays

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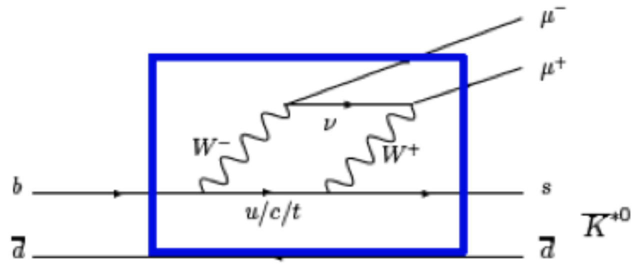
Introduction

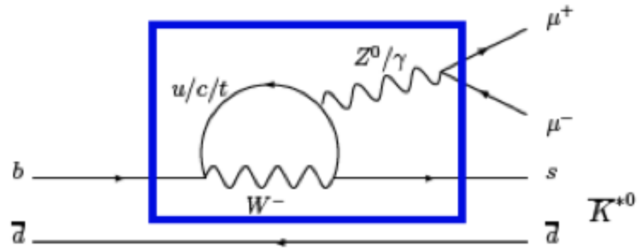
- Interesting set of anomalies have appeared in measurements of $b \to sll$ decays :
  - Angular observables in $B^0 \to K^{*0}\mu\mu$
  - Branching fractions of several of $b \to sll$ processes
  - Lepton-flavour universality ratios in $b \to sll$ decays

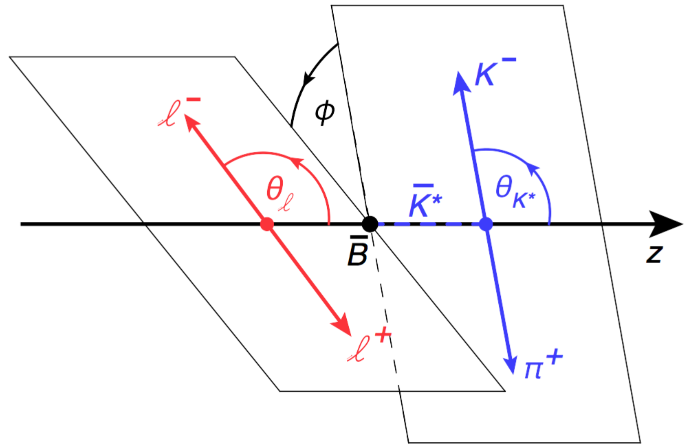
- Extent of discrepancies depends on several theoretical issues – will try and highlight where experiment can provide some future input into these issues

b→sll decays

- b→sll decays involve flavour changing neutral currents → loop process
- Best studied decay $B^0 \to K^{*0}\mu\mu$
- Large number of observables: BF, A_{CP} and angular observables – dynamics can be described by three angles (θ_l, θ_K, ϕ) and di-μ invariant mass squared, q^2

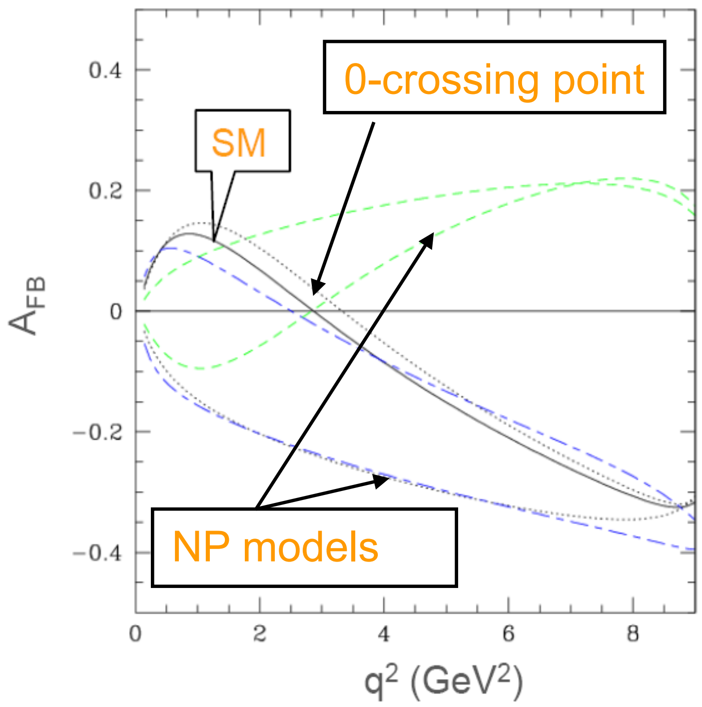


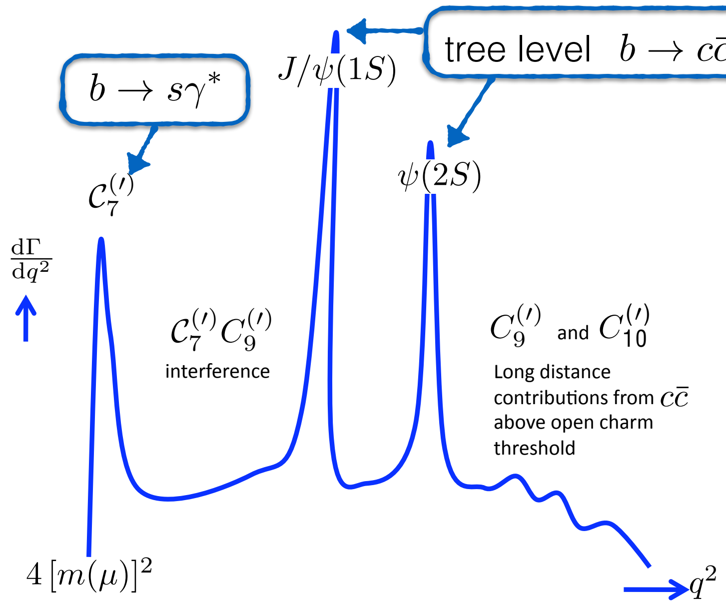




$B^0 \to K^{*0}\mu\mu$

- Try to use observables where theoretical uncertainties cancel e.g. Forward-backward asymmetry A_{FB} of θ_l distn
- Interpreted in effective field theory describing couplings (C) of photon (O_7), vector (O_9) and axial-vector (O_{10}) operators

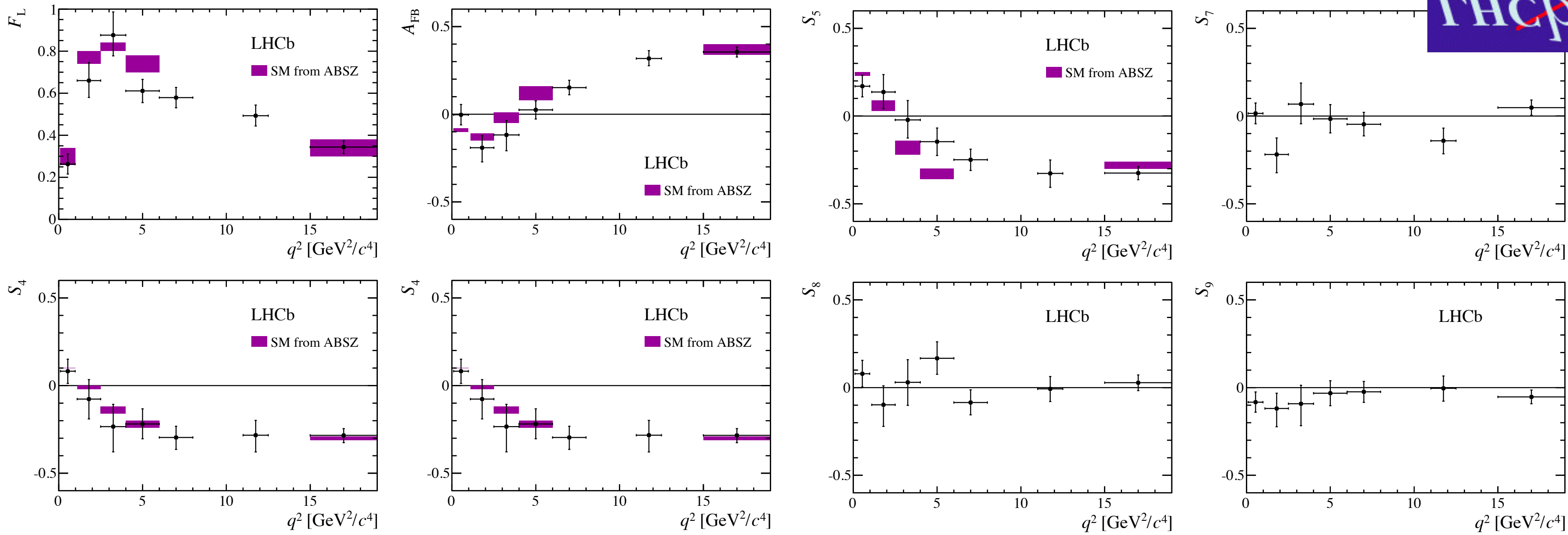




dimuon invariant mass squared, q^2

$B^0 \to K^{*0}\mu\mu$ angular analysis

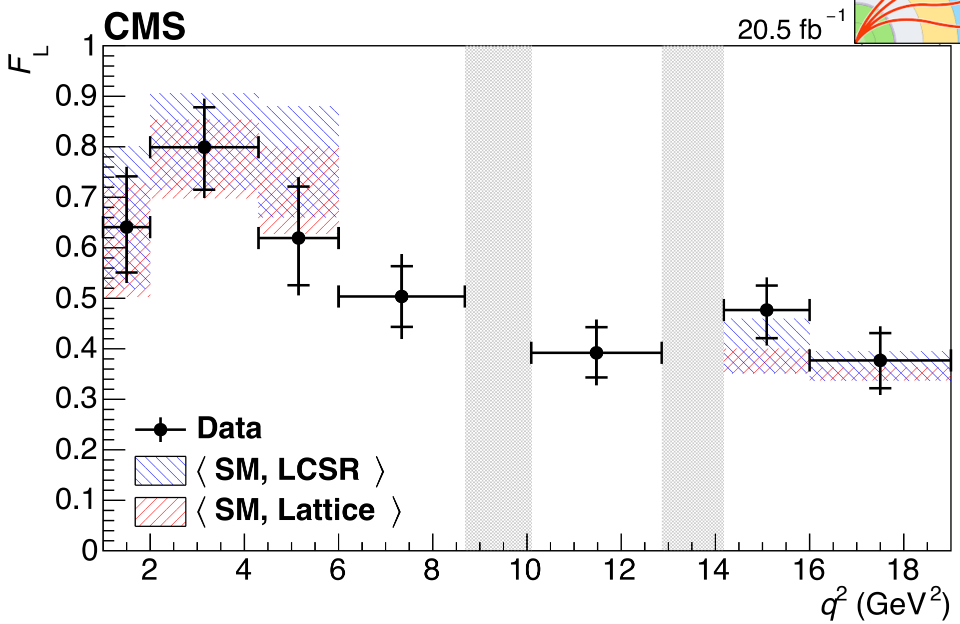
- LHCb performed first full angular analysis [JHEP 02 (2016) 104]
  - Extracted the full set of CP-avg'd angular terms and correlations
  - Determined full set of CP-asymmetries

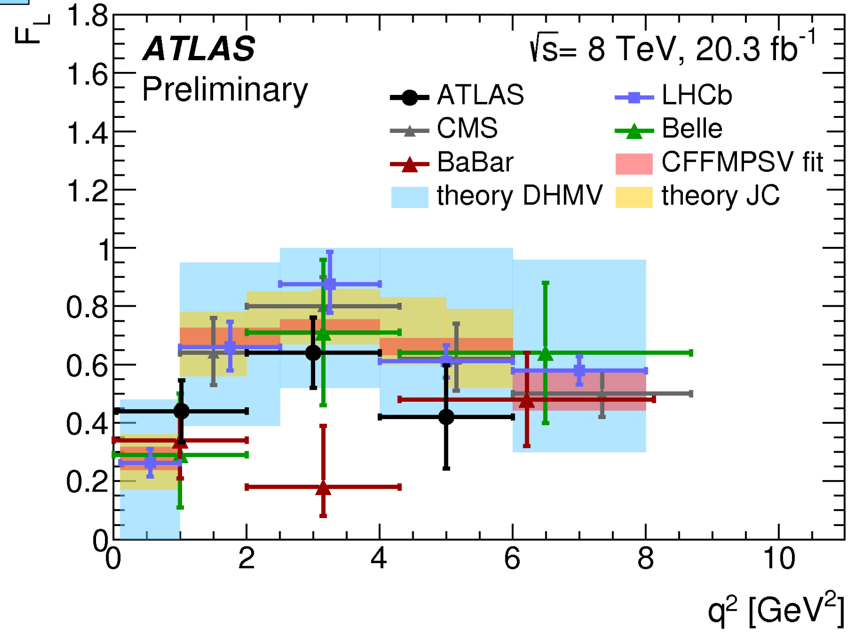


- Vast majority of observables in agreement with SM predns, giving some confidence in theory control of form-factors

$B^0 \to K^{*0}\mu\mu$ angular analysis

- CMS and ATLAS confirm these findings

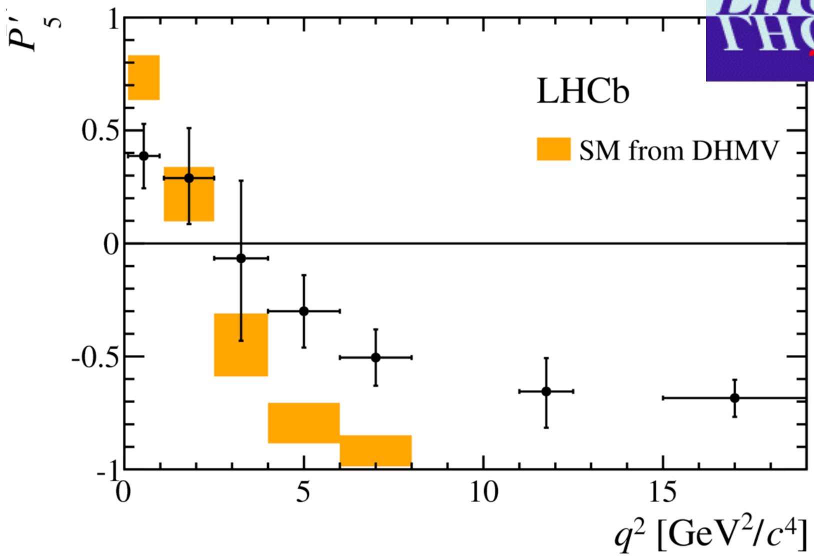




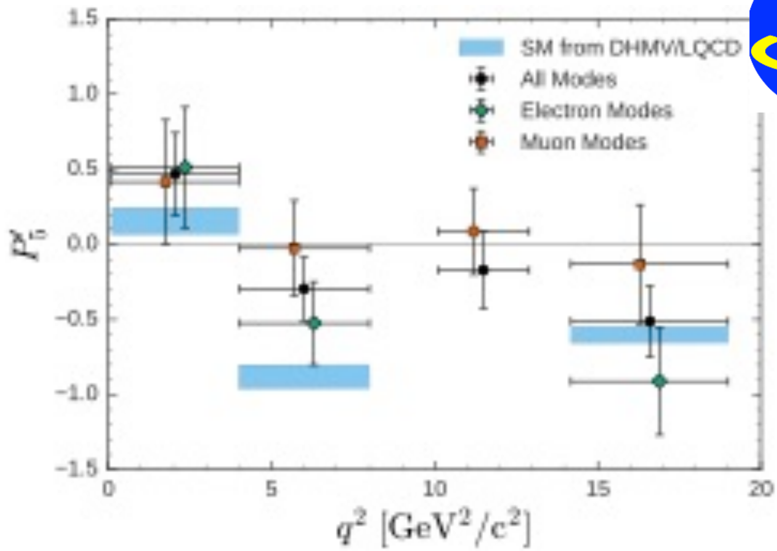
[Phys. Lett. B 753 (2016) 424] [ATLAS-CONF-2017-023]

$B^0 \to K^{*0}\mu\mu$ angular analysis

- In SCET/QCD factorisation can reduce to just two form-factors- can then construct ratios of observables which are independent of form-factors at LO [JHEP 1204 (2012) 104]



[JHEP 02 (2016) 104]



[PRL 118 (2017) 111801]

- Form-factor “independent” P_5’ has a local discrepancy in two bins – (subsequently confirmed by Belle)

  → **3.4σ** discrepancy with the vector coupling **ΔC_9 = −1.04±0.25**

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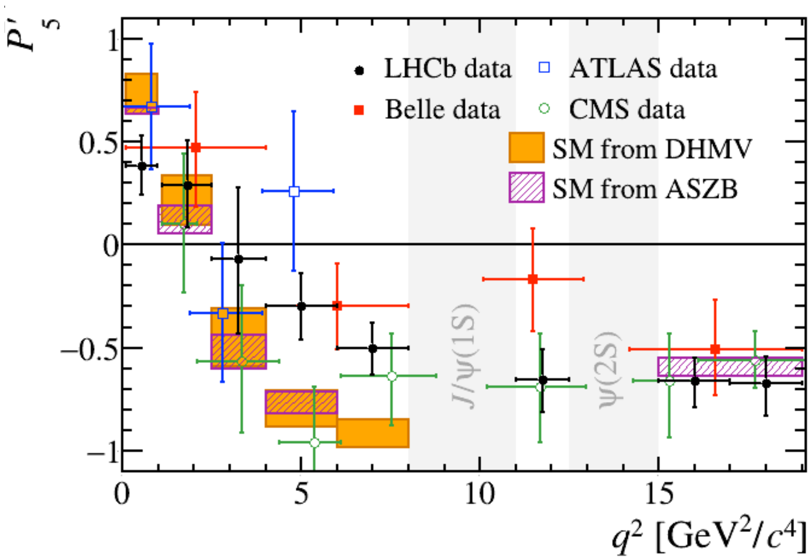

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[PRL 118 (2017) 111801]
[ATLAS-CONF-2017-023]
[arXiv:1710.02846]

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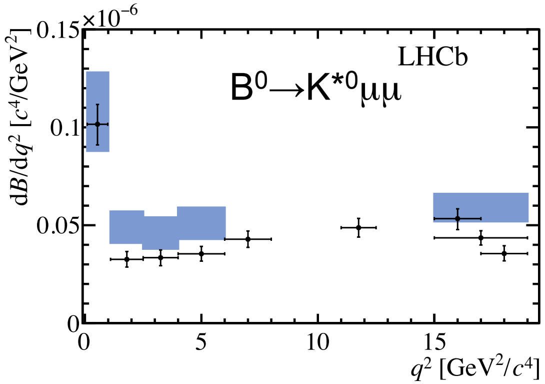
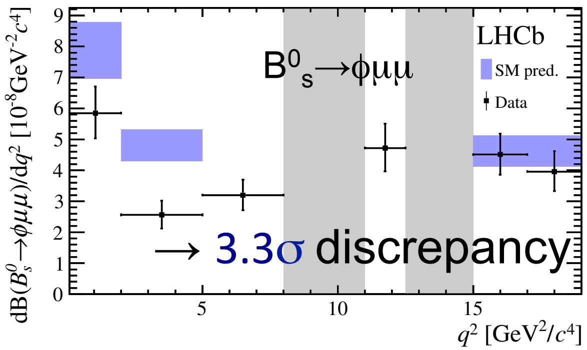
b→sll branching fractions

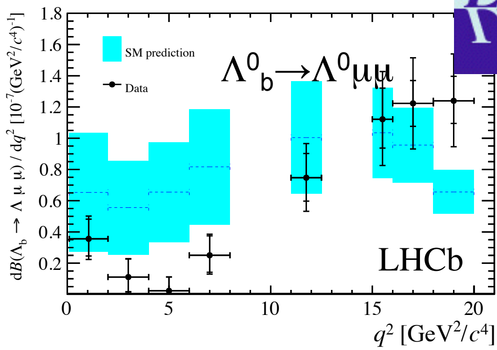
- Several b→sll branching fractions measured at LHCb show some tension with predictions, particularly at low q^2



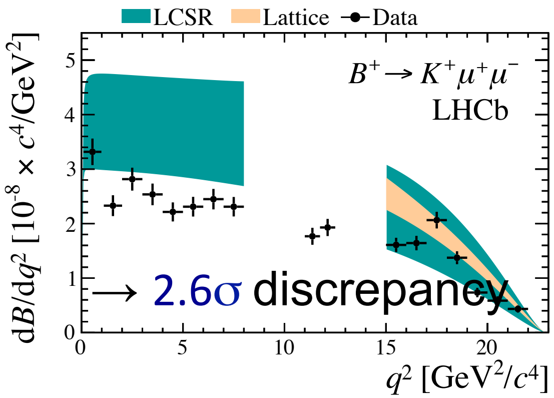
[JHEP 11 (2016) 047, JHEP 04 (2017) 142]

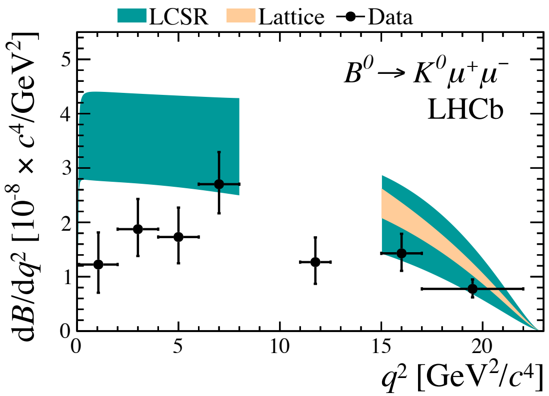


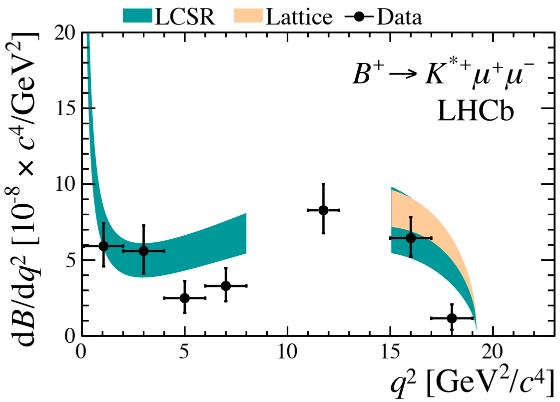
[JHEP 09 (2015) 179]



[JHEP 06 (2015) 115]





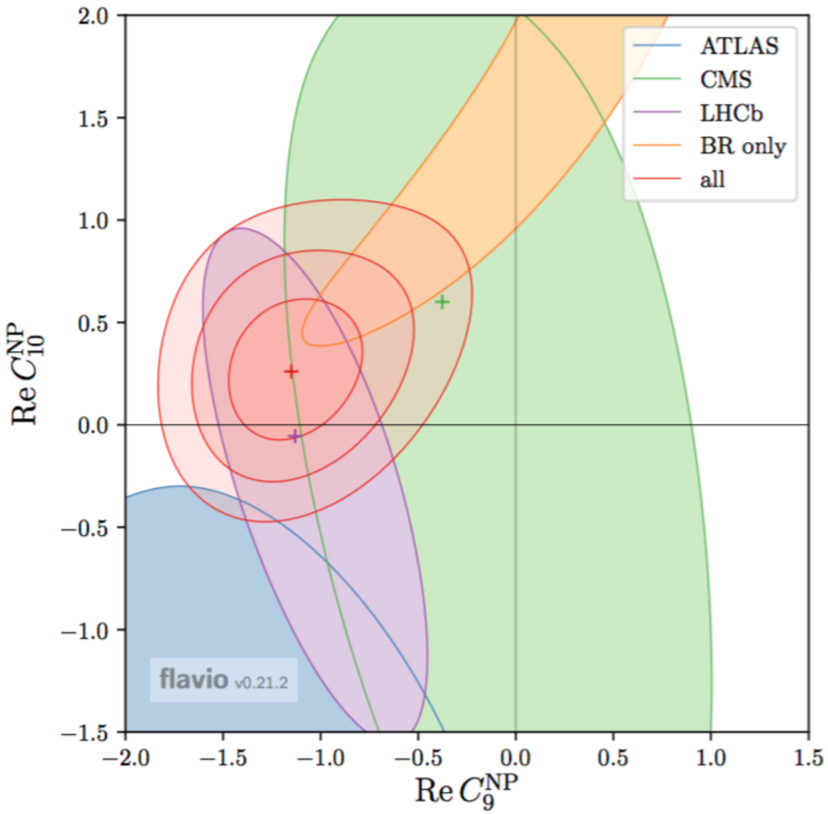


[JHEP 06 (2014) 133]

Global fits

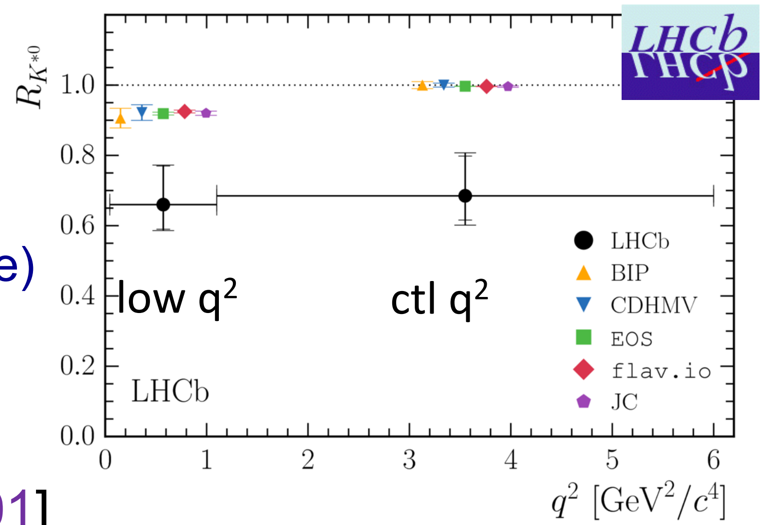
- Several theory groups have interpreted results by performing global fits to b→sll data e.g. [arXiv:1704.05340, EPJC(2017)77:377]

- Consistent picture, tensions solved simultaneously by a modified vector coupling (ΔC_9 != 0) at >**3σ** but discussion of residual hadronic uncertainties (…)



Lepton universality measurements

[JHEP 08 (2017) 055]

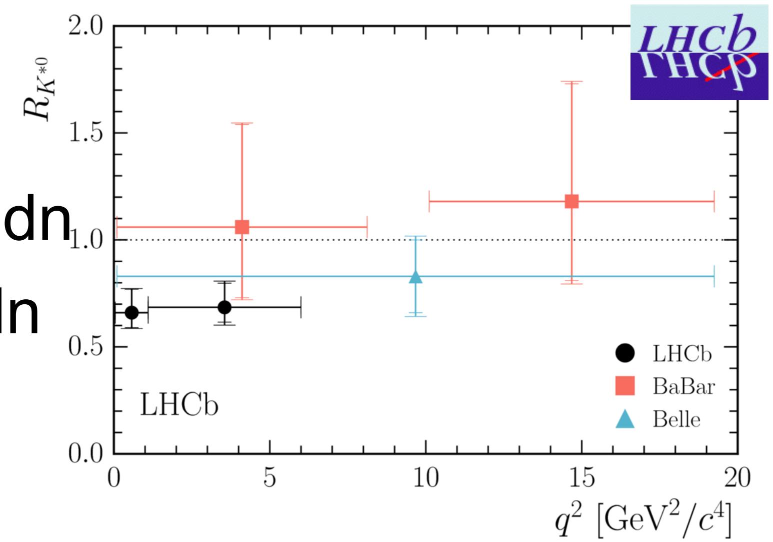


- Whatever hadronic uncertainties affect $b \to sll$ decays, they should cancel in the ratio of BF

  $R_{K^{*0},K} = BF(B^{0,+} \to K^{*0,+}\mu\mu) / BF(B^{0,+} \to K^{*0,+}ee)$

- **R_K** is 2.6σ below SM prediction

  [PRL 113 (2014) 151601]



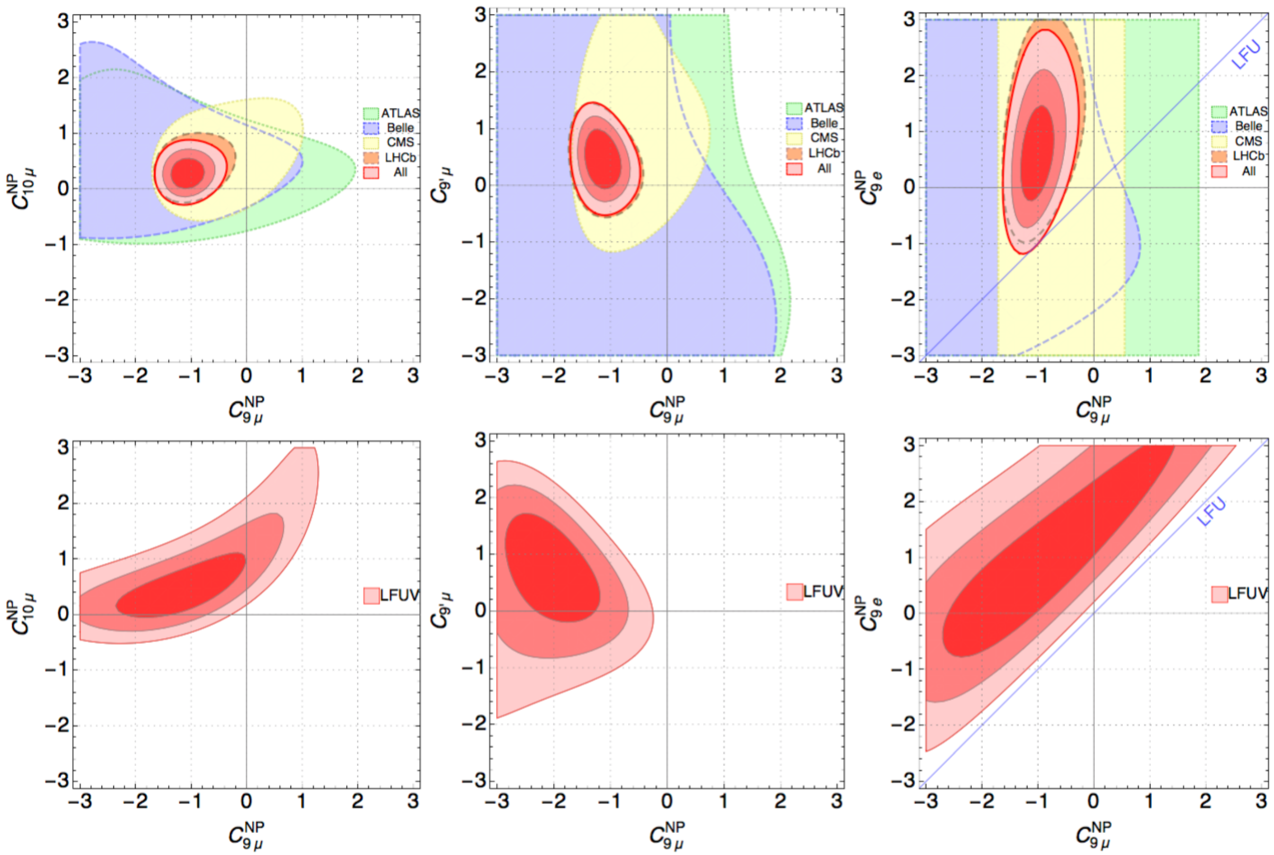
- Recent **R_{K^*}** measurement
  - low q^2 : 2.1-2.3σ below SM predn
  - ctl q^2 : 2.4-2.5σ below SM predn

  Further increases discrepancy

  [JHEP 08 (2017) 055]

b→sll interpretation

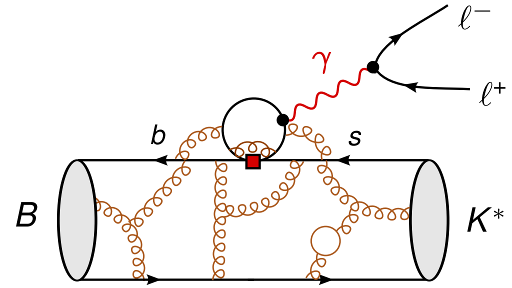
- Adding the LFU measurements in, the size of the discrepancy → >4σ [see e.g. arXiv:1704.05340]



… but community still reluctant to call this NP

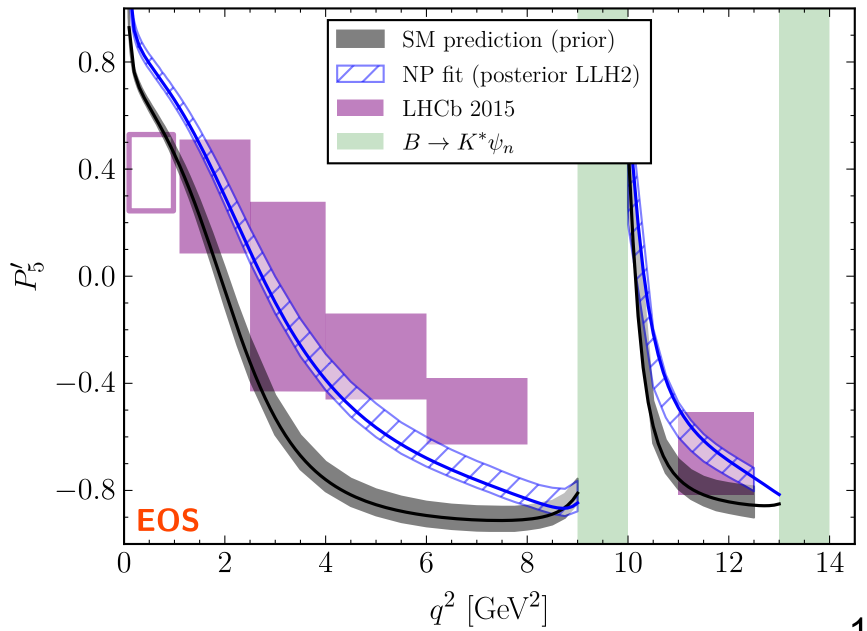
$c\bar{c}$ loops

- Theorists have started to look critically at their predictions – **$O_{1,2}$** operators have a component that could mimic a NP effect in **C_9** through $c\bar{c}$ loop



- Recent paper fits parameterisation to theory and auxiliary data to try and determine $c\bar{c}$ effect

  [**arXiv:1707.07305**]

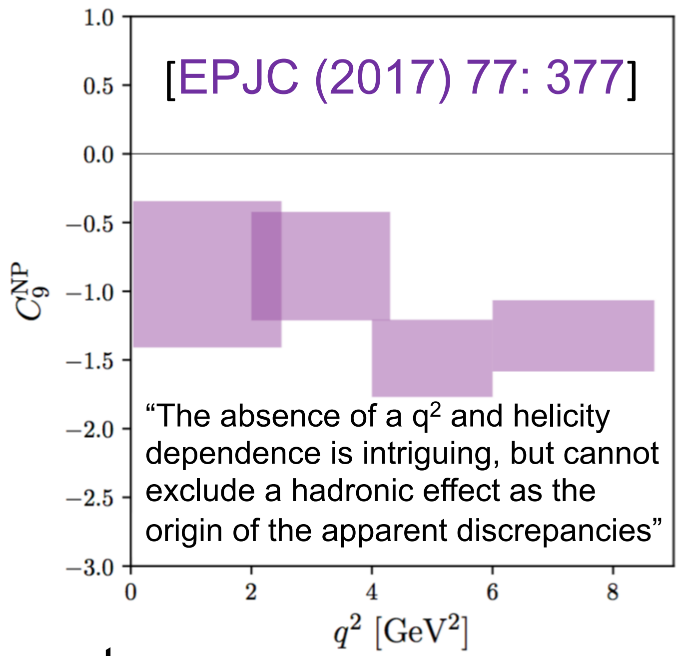


$c\bar{c}$ loops and near term prospects

- Effect can be parameterised as function of three helicity amplitudes, $\mathbf{h_{+-0}}$
  - Absorb effect of these amplitudes into a helicity dependent shift in $\mathbf{C_9}$,

    $$C_9^{SM} + \Delta C_9^{+-0}(q^2) \quad \text{cf.} \quad C_9^{SM} + \Delta C_9^{NP}$$

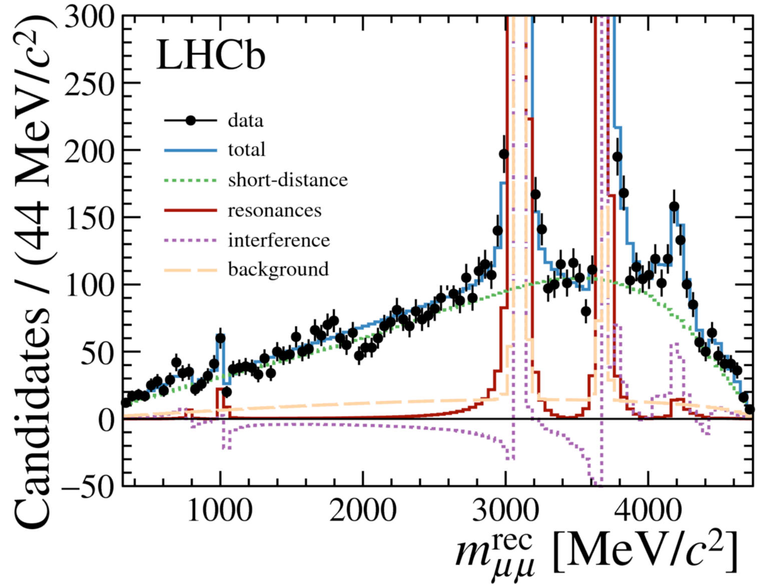
    → Look for $\mathbf{q^2}$ and helicity dependence of shift in $\mathbf{C_9}$

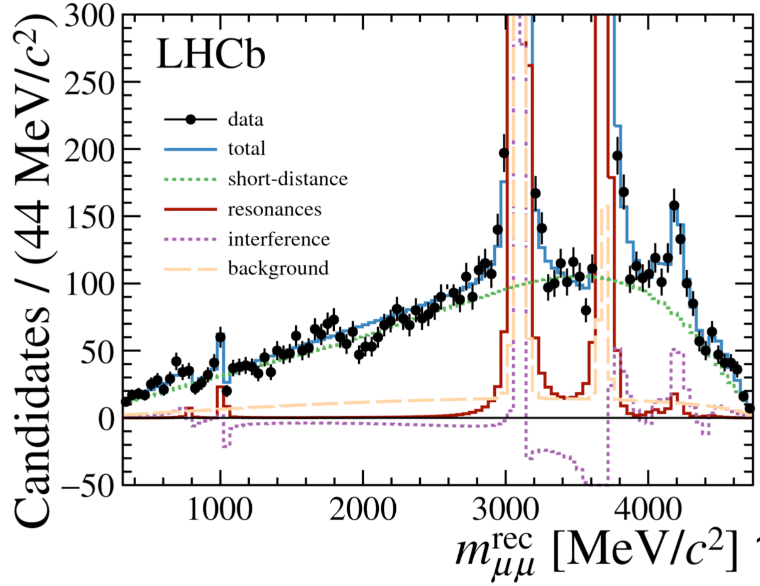


- In near term, will add more Run 2 data e.g. at LHCb :
  - $B^0 \to K^{*0}\mu\mu$ angular analysis ~√2 improvement
  - Ditto R_K and R_{K^*} updates
  - New decays → R_ϕ, R_Λ
  - Measure R ratios for CKM suppressed decays

A glimpse of the future

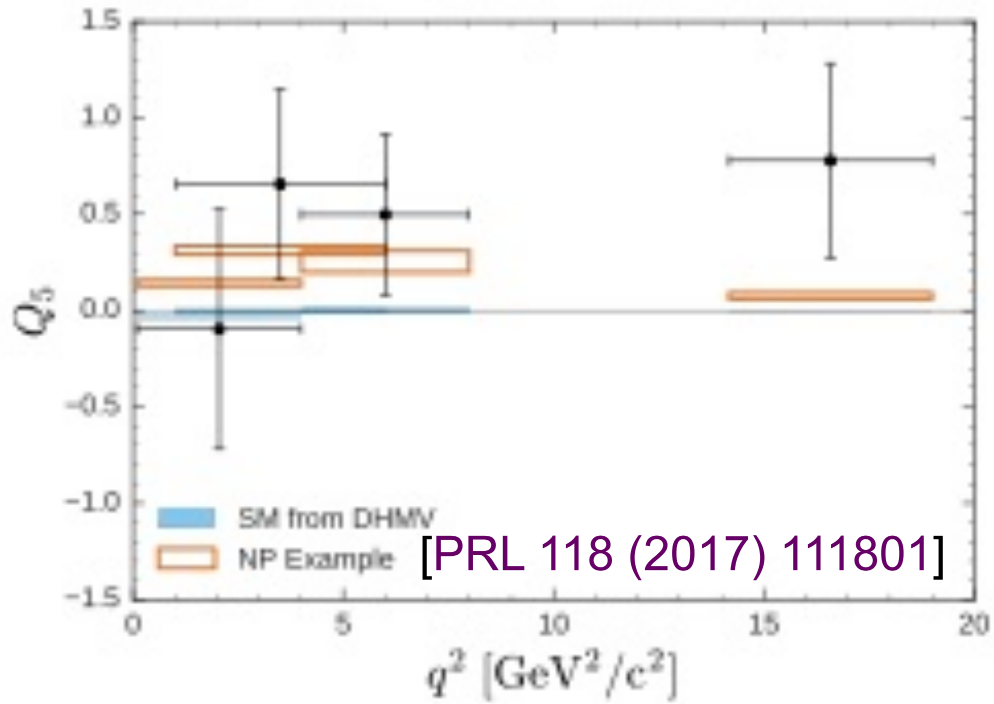
- At low q^2, $\Delta C_9^{+-0}(q^2)$ term arises mainly from interference rare decay and J/ψ
- Measure phase of interference by fitting differential rate (and angles)
- LHCb has performed such a fit for $B^+ \rightarrow K^+\mu^+\mu^-$ [EJPC (2017) 77:161], considerably more complex for $B^0 \rightarrow K^{*0}\mu\mu$ but principle the same





A glimpse of the future

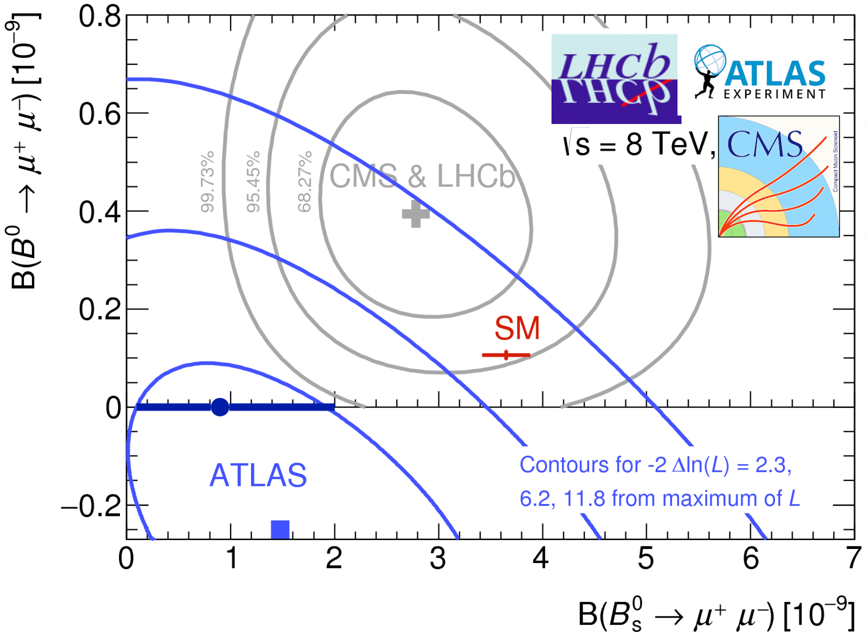
- Can make ratio of $P_5'(e)$ and $P_5'(\mu)$ $\rightarrow$ Q_5
- Thus far, only done by Belle – full angular analysis of $B^0 \rightarrow K^{*0}ee$ in progress at LHCb



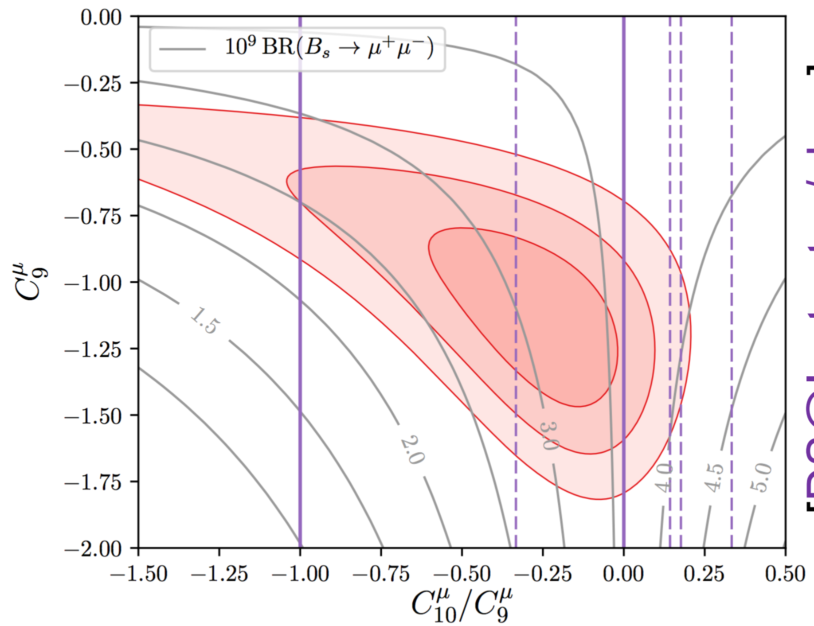
[PRL 118 (2017) 111801]

$B^0 \rightarrow \mu^+\mu^-$ branching fractions

- Single-particle explanations of anomalies predict **$C_9^{NP} = -C_{10}^{NP}$**
  Global fits are still compatible with such a solution
- Would then expect to see an effect in $B(B^0 \rightarrow \mu^+\mu^-)$ decays
- No evidence for any deviation from SM so far…



[Nature 522 (2015) 68]
[EPJC 76 (2016) 513]



[DS@Instant w/shop]

Conclusions

- Interesting set of anomalies observed in B decays – given experimental precision and theoretical uncertainties, none of them are yet compelling
- Near-term updates should clarify the situation and can help constrain some of the theoretical issues
- Wide range of new measurements will be added to broaden the constraints on the underlying physics
- At LHCb, full Run-2 dataset will give factor ~4 more data than Run-I on timescale that Belle-2 will start running. ATLAS/CMS will also be able to contribute in a number of cases

Cross-checks

- Control of the absolute scale of the efficiencies is tested by measuring

$$r_{J/\psi} = \frac{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to \mu^+\mu^-))}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to e^+e^-))}$$

- Expect unity in SM
- Does not benefit from the large cancellation of experimental systematics
- Measure 1.043±0.006 (stat) ±0.045 (syst)
- Result is independent of the decay kinematics